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OUTLINE OF COST-BENEFIT ANALYSIS AND A CASE STUDY

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INTRODUCTION

The early man had to defend himself when attacked, but otherwise concerned himself with securing food and shelter. Today things are more complex for the individual as well as society. There are hundreds, indeed thousands, of tasks and needs to be addressed or attended to. Available resources are limited. Economic analysis constitutes a means of allocating scarce resources - whether they be capital, labor, management, R&D and/or equipment to competing needs.

Economics is subdivided into micro- and macroeconomics. Microeconomics studies the behavior of individuals and markets, whereas issues related to a nation would be classified under macroeconomics. The study of Government expenditures is generally referred to as welfare economics. (This is not to be confused with the administration of a welfare program within a given level of Government.)

Understandably there is a host of competing ends for the Government dollar, and Government revenues or sources of income are alas limited. Hence some kind of "rationing" is involved in allocating or appropriating funds for education, defense, agriculture, space, or other programs. Even after funds have been appropriated, say, to NASA, decisions have to be made as to which programs within NASA are to be undertaken and which are not to be undertaken. (The actual budget process essentially reverses the order indicated here. Nevertheless, the principle is not altered.) How are public programs, then, to be awarded or denied funding? In essence, projects that contribute more to a society's well-being and welfare should receive funding. For example, if two undertakings cost the same, but the first resulted in more benefits to society than the second, it is reasonable that the first would be funded - given that available funds are enough for one of the two only. Cost-benefit analysis, alias cost effectiveness, seeks to provide such comparisons.

Historically, the 1936 Flood Control Act probably represents the earliest documented example of benefit-cost philosophy applied to federal programs; it, in essence, permitted the Federal Government to undertake water projects for flood control purposes . . . if the benefits to whomsoever they may accrue are in excess of the estimated costs . . . .

Starting in 1964, DOD required that alternative weapon systems be evaluated based on cost, schedule, and effectiveness. In 1965, President Johnson asked all Government agencies to adopt a similar system. Later in 1965, the Bureau of the Budget issued Bulletin No. 66-3 which stipulated that benefit-cost analysis was to be used in selecting programs to meet the goals of the various Government agencies.

This report introduces the technical reader to the area of cost-benefit analysis (CBA), a branch of economics. The report has two objectives: (1) To provide a technical person an adequate background to conduct a reasonable CBA study, and (2) To give a decision maker the ability to understand and evaluate the results of such a study.

A technical person not trained in economics should plan to engage in some readings in economics before carrying out a CBA study. A suggested reading list is included. This report does not presume any background in economics, but such a background would provide a worker with sensitivity to the concepts involved.

The present work would not be adequate for analysis of undertakings requiring investments of the order of tens of millions of dollars or more. Trained economists should work on such efforts.

OVERVIEW OF COST-BENEFIT ANALYSIS

Cost-benefit analysis measures or ranks the desirability of projects where the long-term view is essential. (The same principles apply to a one- or two-year horizon, but such a time span usually has fewer unknowns, fewer assumptions, and less uncertainty.) The end result is a comparison of the economic differences between and among available alternatives. In other words, the analysis seeks to establish the relative merits of the various alternatives versus each other rather than the total or absolute merit of one or all options.

The analyst seeks to define the problem, catalog all direct and indirect costs and benefits, and state clearly all assumptions made in the process. Next, all quantifiable direct benefits and costs are expressed in some common units; hopefully, dollars. At this point, the costs and benefits are discounted to the present in order to compare on the same time basis. (Present value is discussed in a later section.) Two comparisons are now possible:

$$\text{Benefit-Cost Ratio (BCR)} = \frac{\text{Present value of benefits}}{\text{Present value of costs}}$$

$$\text{Net Present Value (NPV)} = \text{Present value of benefits} - \text{Present value of costs}$$

A third comparison, the internal rate of return (IROR) can also be computed, by trial and error such that NPV = 0, and is discussed later.

The remaining work represents the major portion of the study. It consists of documentation of the problem, the data, analysis of results, and a full discussion of indirect costs/benefits and intangibles. It is important to note that intangibles are not necessarily indirect effects, rather they are effects that cannot be quantified. Examples would be satisfaction, security, and prestige. Another class of effects, incommensurables, consists of outcomes that are quantifiable but not in dollar equivalents, such as the number of lives saved. Some management scientists argue that the greatest value of a study lies in the identification of any significant intangibles and/or incommensurables. This is so because these effects do not appear in the numerical data and analysis - which are often confused for a "solution" to the problem.

SPILLOVERS (EXTERNALITIES)

An activity or undertaking results in effects or outcomes; some are direct while others are indirect. Thus, production generates a product - which is the objective. The undertaking also leads to hiring a work force, contributing to pollution, providing tax revenues, increasing/decreasing property values, consumption of natural resources, altered transportation practices, increased/decreased profits plus a host of other effects of varying magnitude. Those effects which follow production, but were not intended, are referred to as spillovers, neighborhood effects, side effects, external economies and external diseconomies, or simply externalities.

While no tabulation of spillover effects is complete, an effort must be made to account for and discuss the more important ones. There is, however, the danger of double counting which an analyst must avoid. For example, consider a product worth $100 that led to employing $30 of labor. Of course, labor wages represent a benefit, but to report that the said product resulted in $130 of benefits double counts wages which already appear in the value or price of the product. The same would be said for profits, shareholders revenues, or income taxes. In other words, CBA is not altered whether a benefit accrues to individual x, individual y, company z, local or national Governments. Economic analysis in the present context concentrates on benefits/disbenefits to whomsoever they may accrue in society. This does not preclude mention of the desirability of, say, locating a facility in a chronically underemployed region as long as no double counting is involved.

Cost-benefit analysis compares benefits to costs for a given investment. The comparison includes some spillovers, referred to as technological spillovers. There are two classes of spillovers or externalities, technological and pecuniary. Considering that only one of the two classes is to be included in the numerical comparison, it is imperative that the subtle distinction be understood. (While pecuniary externalities are not formally included in the cost-benefits comparison, the discussion should bring out any significant pecuniary spillovers.)

Pecuniary spillovers encompass those financial and related effects of an investment that would reasonably follow from an equivalent expenditure. Thus, a small country may suddenly find its treasury overflowing with revenues from a new plant. All the increased services provided the country's residents through the new tax revenues are pecuniary spillovers. Pecuniary spillovers are not included in CBA studies.

Technological spillovers relate to resource utilization and availability. Thus a power plant may add to a nearby river all the thermal "enrichment" permissible under the law. A downstream plant then might not be able to dispose of its waste heat into the river; this plant has to invest in other expensive equipment to handle its waste heat. This additional expense incurred by the downstream facility is a technological externality that should be included as a disbenefit in evaluating the BCR of the power plant upstream.

Another example of technological spillovers would be the effect of the new plant on labor supply. The increased demand for labor in the geographic region of the facility may lead to higher wages demanded and received by the labor force. Now, other employers are having to pay higher wages. This incremental increase in wages paid by other employers must be counted as a technological spillover and entered as a disbenefit. (This incremental increase in wages because of demand for labor by the new plant is not priced in the facility accounting; someone else pays for it!)

The two types of spillovers are not always easy to tell apart and frequently overlap. The important point is to identify the major technological spillovers which are usually the cost drivers among the spillovers.

LIMITATIONS OF COST-BENEFIT ANALYSIS

The application of economics suffers from the kind of weaknesses characteristic of all social sciences. A cost-benefit study incorporates in it four dimensions of limitations; these are not equally serious nor entirely insurmountable. However, none of them may be eliminated.

(1) Intangibles and quantifiables. Certain variables, like costs, are generated in dollars; even those, however, are estimates of future prices. In the area of quantifiable benefits, on the other hand, more uncertainty is involved in

converting all forms of benefits to a common measure such as dollars. But many factors are intangible and thus defy expression as dollars.

(2) Future and uncertainty. In the preceding paragraph, uncertainty in estimates of future costs and benefits was mentioned. Another dimension of this phenomenon deals with factors, outcomes, and effects that are entirely unforeseen at the present and hence do not appear (as assets or liabilities) in the analysis. Also critical in any cost-benefit analysis is the choice of a discounting factor - which is at best a guess.

(3) Analyst bias. (This is innocent, uncontrollable bias which does not carry a connotation of "bad.") This kind of subjectivity or bias creeps into a study in two ways:

(a) An analyst is usually more versed or acquainted with one alternative, or one part of an alternative such as costs.

(b) Sometimes a worker has taken a position vis-a-vis one alternative before completing the study.

(4) Organizational bias. Organizational competition is not unusual. When a study is comparing alternatives fostered by different teams, there is a tendency, if subconsciously, to favor "our" proposal.

How could these limitations be overcome? They could not be entirely eradicated; they could, rather, be minimized. The best approach for that appears to be in making these limitations clear and known to both the analyst as well as the manager.

PRECAUTIONS

Cost-benefit analysis is a management decision making tool. Like management itself, this tool remains a blend of art and science. Why not, then, leave it to a manager to apply his art and science to a given situation? It must be emphasized that a cost-benefit study does not in any way reduce a decision maker's options, it only brings into focus relative economic advantages of various available alternatives.

A person trained in engineering or science frequently has difficulties in appreciating the value and limitations of economic analysis which, of necessity is not exact. Economics deals with an area of study that is behavioral in nature and hence is not quantifiable or measurable in the same sense as engineering, chemistry, or physics.

Cost-benefit analysis, per se, deals with future events, and human ability to predict future outcomes is very limited. We usually have to deal with extrapolations, estimates, and even guesses. This means that two analysts separated by distance and time would be expected to have different findings when studying the same phenomenon. Subjectivity and experience of the analyst, for one thing, affect the outcome of such a study. Even if the same investigator were to undertake the same cost benefit study twice, two or five years apart, he would likely arrive at different results and conclusions because the passage of time reduces uncertainties and reveals previously unforeseen, yet relevant, parameters or factors. All the uncertainty and other weaknesses that afflict economic analysis, however, do not deem it incorrect or useless. If exact answers were called for, one would need to overcome two problems: (1) predicting the future which introduces uncertainties and inaccuracies; and (2) eliminating uncontrolled factors which entails maintaining society in a laboratory environment. Neither of these two dimensions of management decisions can be eliminated.

CBA, conceptually, measures costs and benefits to society from a given undertaking. This, however, is easier said than done; a worker is generally more familiar with: one agency, one field of technology, one sector of the economy, one region of the country, one type of outcome (namely, benefits), and the present and near-term effects.

What this adds up to is that it is difficult and time consuming to carry out a complete assay or measurement of costs and benefits relevant to a study. Therefore, we usually accept some compromise, or trade off, between completeness and timeliness/costliness.

This is not to encourage incompleteness or oversight. To the contrary, it is to sharpen an analyst's awareness of this problem calling for extra attention to and study of these areas where one's preparation is lacking and insufficient.

PRESENT VALUE

This is the familiar "time value of money" concept, that a dollar received today is worth more than a dollar received one or two years later.

"A future dollar" may be discounted back to the present as follows:

$$PV = \frac{1}{(1 + i)^N}$$

where

PV discounted present value, $, of a future transaction

i interest or discounting rate

N number of years before transaction takes place

Thus, if the rate of discount is 10 percent, $100 today and $121 two years later are equivalent - in economics jargon "we are indifferent" to the two transactions.

An annuity is a related concept. It represents a payment recurring at equal intervals in the future, like mortgage or car payments. The present value of an annuity is expressed as:

$$PVA = \sum_{N=0}^{K} \frac{A}{(1 + i)^N}$$

where

PVA value of annuity expressed in today's dollars

K number of periods, years

N 1, 2, . . ., K

A recurring value of annuity

i discounting rate

Thus, to finance a $4300 auto loan at 15 percent for 36 months, the monthly payment, or annuity, would be $150. Mathematically,

$$PV = \$4300 = \sum_{N=0}^{36} \frac{150}{\left(1 + \frac{0.15}{12}\right)^N}$$

A source of confusion should be pointed out. The above auto loan cost $4300 to an economist, but cost $5400 or $150 × 36 to an accountant. In accounting, and budgeting terms, a dollar spent today and a dollar spent two years later are both entered as $1 each; in other words, the time value of money is not recognized from a bookkeeping standpoint - thus the term, accounting dollar. An accounting dollar is one that is spent or received any time. Whereas 1976 dollars are those spent/received during 1976 or those discounted back to 1976 by the PV formula.

INTERPRETATION OF DISCOUNTING OR INTEREST RATE

The conclusions of an analysis would vary depending on the rate of discount used. Thus analysis may indicate one alternative to be superior to another, but that finding could be reversed at a different rate of discount. What, then, is the correct rate of discount? There is no such a quantity!

The discounting rate used for a public undertaking represents a balance between two rates. A social rate of time preference and a social rate of return on investments. (No rigorous definitions will be attempted here considering the economic background required, but a general view is given.) A rate of time preference reflects a society's valuation of future benefits. For example, how much do we presently value the availability of petroleum to future generations? A rate of return on investments relates to the return expected from a public investment of the same amount. The two rates are not equal and hence a compromise is not straightforward.

In order to minimize confusion about what rate of discount to use and to standardize discounting in all CBA's undertaken by Federal agencies, OMB has issued Circular No. A-94 Revised (March 27, 1972). The circular stipulates that essentially all Federal agencies shall use a discounting rate of 10 percent. This should be checked periodically since OMB may change the rate as time passes.

COST-EFFECTIVENESS

Cost-effectiveness (CE) is an economic technique similar to CBA except in the type of problems where it is applied. In CBA, quantification in dollars of as many costs and benefits as possible is sought. But some problems do not lend themselves to such analysis. Chief among this class of problems is the defense area; expressing benefits of a defense system in dollars is not useful or possible. Instead, a new system is evaluated in terms of its effectiveness and its contribution to the overall preparedness of the defense effort. (Preparedness is evaluated by simulation and game theory techniques - which are beyond the realm of this discussion.)

Effectiveness is a measure of how well a system performs its function in various operational conditions. Here, again, interesting problems arise. A system may perform a very good job in one aspect of its mission, but in another circumstance may be ineffective or less effective. The problem, clearly, is in expressing these two divergent performances in one measure of effectiveness!

Fortunately this does not have to be treated here and is mentioned only for competeness.

INTERNAL RATE OF RETURN

A reasonable number of public expenditures receive cost-benefit treatment. The internal rate of return (IROR) is also used to compare projects. There is no reason that this criterion could not be an integral part of every economic study; all the data are ready for the IROR analysis.

Cost-benefit analysis reveals the ratio of benefits to costs at a given interest rate. IROR represents the interest or discounting rate at which costs equal benefits (NPV = 0).

$$NPV = \sum_{N=0}^{K} \frac{(B_N - C_N)}{(1 + IROR)^N} = 0$$

where

B benefits, $

C costs, $

N 1, 2, . . ., K

Table I shows the steps involved in arriving at IROR by a trial and error solution. As one gains more experience, the number of iterations required is reduced. The method calls for increasing/decreasing the discounting rate systematically until the NPV approaches zero.

Table II depicts two alternatives where the BCR criterion fails to show any difference. (A BCR of 1.8 vs. 1.9 for these cases is basically the same ratio when future uncertainties are kept in mind.) However, the IROR criterion show investment A to be clearly superior.

Table III reflects another example where investment X is superior even though the competitor has a slightly higher BCR at 10 percent.

A situation showing two equivalent alternatives is seen in table IV. In this case each criterion, BCR and IROR, shows one of the two possibilities to be clearly better than the other.

It should be borne in mind that BCR is sensitive to the assumed rate of discount. For that reason we like to use both the BCR as well as the IROR criteria in order to tell whether two or more alternatives are clearly different from each other economically.

WHAT ARE COMPARABLE INVESTMENTS?

Economic analysis techniques covered in this work (CBA, NPV, IROR, CE) generally yield answers of comparable quality. Technicians should understand all these techniques as each method sheds light on a problem from a different perspective. More reliable analyses would utilize CBA, NPV, and IROR in comparing different or alternative undertakings. The BCR provides a comparison of the ratio of benefits to costs for each venture. The NPV yields estimates of excess benefits generated over costs. (Both CBA and NPV methods assume some given discount rate.) IROR of an undertaking reveals its intrinsic rate of benefit generation.

Even while all three tools are used together, there are limitations to the application of economic analysis to expenditures. The ideal would be to provide a decision maker (who has x dollars to spend) with a list of possible expenditures, ordered by decreasing economic value. From this list the decision maker selects the first N projects whose total cost comes to x dollars. In this manner, funds are allocated optimally to the most productive areas. CBA is not capable of providing such rankings. For example, BCR's of social- and defense-oriented programs cannot be compared meaningfully. Not even within the same agency, such as NASA, could one compare all programs based on their BCR's or IROR's. This is not to suggest that the availability of BCR's/IROR's would be of no value. (Other techniques allow comparison of agency-wide or nation-wide programs.)

Projects can be classified as related and unrelated. Unrelated programs, such as defense and social programs, do not lend themselves to CBA treatment as stated earlier. Related programs consist of three types:

(1) Exploration of new areas. Exploratory work is more in the realm of research than development. This would not be subject to CBA unless alternative approaches are possible - which is frequently the case. If no alternatives are clear, this type of work may be compared to the present or "no action" decision and CBA would then be applied.

(2) Supporting, parallel, and series programs. Here is an area where economic comparisons are made frequently and improperly, as seen below:

Expenditure	$	BCR
A	1 M	1.2
B	100 M	1.5
C	2 B	1.5

In the example shown above, it is improper to conclude that C is a better investment than A - considering the level of each investment. Additionally, A may represent work to improve solar cell efficiency, B may represent improved efficiency and lower costs of a total power system for a given mission. Clearly A is a subset of B. Therefore, any comparison of A and B should indicate that A is included in B - if that is indeed the case. C may be a new computer system for a mission. Therefore, it is improper to sav that B and C are equally cost-effective since the BCR's are the same (consider the level of expenditure required by each and consider, too, that the two projects are not comparable as discussed in the next section).

(3) Alternatives or options. This is the area where CBA has its most discriminating power. Alternate approaches that have the same target or end result are suited to comparative analysis for the following reasons:

(a) They usually have different price tags or costs.

(b) Their outcomes are reasonably similar.

(c) Spillovers, good as well as bad, to the economy and society are very similar; these spillovers do not, therefore, need to be quantified except when they differ from one to another option.

In this manner it is possible to reduce estimation and forecasting errors by concentrating only on the areas of dissimilarity among alternatives. Hence, this represents a category where CBA studies would be most effective without calling on trained economists to perform such studies.

PRICES

Cost-benefit analysis deals with projections into the future. The decision maker attempts to balance her/his view between the present and the future, but the future has more uncertainty than the present - especially when it comes to economics. Therefore, a relevant question arises as to what prices should be used for costs and/or benefits taking place in the future.

No simple answer is available; however, some guidelines are provided. Assuming the factor is priced at the time of a study, its current price is used as a base. This base price is augmented or adjusted in order to reflect:

(1) Expected technology. Any foreseen changes due to resource availability, manufacturing methods, marketing approaches, which would affect the price/performance of the factor should be included.

(2) New markets. If a factor is expected to penetrate into uses not occupied currently, then this increased demand/supply will have an effect on price levels and should be considered.

(3) Learning curves. Industrial engineers have made good progress in estimating reasonable impacts of learning experience on prices and costs. Such factors are included in projections.

(4) Expected factor prices. Frequently, price changes are known in advance due to contractual obligations. For example, a labor contract may call for a 10 percent wage increase over a three-year period; such a price effect may be considered in projections.

(5) General price level (inflation). The first thought that comes to mind when projecting prices to the future is accounting for inflationary effects. This intuition is misleading. While this treatment cannot fully address and explain inflation, two points should be brought out: (a) economists have not been able to explain inflation or why it occurs successfully to this date, and (b) including anticipated inflation in projections would lead t effectively doubling actual inflation rates. Hence it is important to resist the temptation to include this factor in the projection of future prices.

The remaining question would be that of arriving at a future price given today's price. Unfortunately, no formula is available which incorporates the above factors and determines a price level of an input factor in the future. A combination of judgment, intuition, and experience are called for, and then the answer is only an estimate.

There is frequently a tendency to "beef up" estimated prices because project costs are always underestimated. It is wise to resist such a tendency - unless benefits are also beefed up considering that benefits are also underestimated - but receive less scrutiny!

OPPORTUNITY COST

This is a key economic concept that has not been brought into the CBA discussion. Its omission const tes one reason the applicability of CBA has bee restricted within this report In the most general applications of CBA, opportunity cost ould not be overlooked; one or more economists would be involved in such a study. As suggested elsewhere, CBA as outlined here may be ap lied usefully to alternative problems.

Opportunity cost may be thought of as what we miss or do without when we invest in the alternative under consideration. Consider for example a family trying to decide whether or not to buy a new car. In light of their financial situation, they are aware that should they proceed to buy a new car, it would mean a three-year postponement in the expansion of their existing house. Hence, the opportunity cost of buying a new car for this family is the postponed satisfaction from an expanded house.

Within a Government budget, a proposed defense program may lead to a delay in n educational program. The opportunity cost of the given defense system is, therefore, the foregone so ial value derived from th postponed or abandoned program

Trying to brir t e concept of opportunity cost into CBA is, owever, much more complex tha pears from these examples. Refined econor ic tools would be needed which ultimately would call for training in economics beyond a brief introduction. The objective of the current work was set to provide methodology allowing a practicing engineer to make reasonable economic comparisons among alternatives without need for a trained economist.

CASE STUDY - ECONOMICS OF SOLAR CELL DEVELOPMENT

This case study demonstrates the application of economic analysis (cost-benefit methodology) to proposed space expenditures. The work comprises an evaluation of the economic merits of proposed R&T efforts in the area of space silicon solar cells over the years 1977 to 1982.

Cost-benefit analysis provides an assessment of the economic worthiness of an undertaking. This methodology compares benefits to costs on the same time basis. All cash flows are discounted at the rate of 10 percent as outlined in OMB guidelines. The analysis does not address noneconomic considerations which are pertinent in decision making, such as social, political, and environmental factors.

Problem

R&T funding has been proposed for solar cell development. This economic analysis concentrates on proposed activities leading to reduced weight, improved efficiencies, and lower costs of space silicon solar cells. The appropriation of funds is to be contained in the 1977 to 1982 budgets; these expenditures are summarized in table V.

The proposed improvements in cell technology are highlighted in table VI. The present efficiency of 13.5 percent represents the current space qualified cell, whereas the development effort is geared to produce a cell that is 50 percent lighter and much cheaper - without sacrificing cell efficiency. Justification of the expenditure is seen in the reduced weight and cost of such cells.

It is not clear at this point whether some missions would be weight-constrained. (However, in the case of the Satellite Power System (SPS) prototype, it is likely that some number of launches may be saved at an estimated cost of $20 million per launch.) Additionally, the overall weight saving in the solar array is not clear; therefore, no credit is claimed in this study for weight savings. This renders the analysis to be conservative. The only savings included directly in the analysis are those resulting from lower cost.

Current cost of space solar cells is about $100/W with a target reduction to $5/W by 1981-1982. This represents the only direct benefit of the proposed

R&T effort as computed in this study. This, in a sense, is conservative considering that weight savings are also likely. On the other hand, the achievable cost reduction is speculative considering the time element.

The analysis presented here is based on two main scenarios of potential or possible levels of space programs and activities extending from the mid-80's to the end of the century. These scenarios do not represent a set of defined missions that are on "the drawing boards," rather they consist of a projection of two levels of activity, one being aggressive and active (may be viewed as optimistic), the second being reasonable and realistic. The missions shown in table VII are only educated guesses or candidates. Understandably, experts would not agree on reasonable estimates of space activity 8 to 23 years in the future in the absence of a national space program. However, that does not detract from the usefulness of such analysis from the decision maker's standpoint - he is offered a better means of assessing the future.

Estimation of program benefits is simple once cost reductions and activity scenarios are established. (Luckily in NASA work, direct spillovers are minimal which simplifies the analyst's task.) The benefits shown in table VII represent the product of projected cost savings ($95/W) times "estimated" Government purchases of space solar cells.

Results and Discussion

Once the scenarios of space activity are set up, the computational aspect is mechanical and algorithmic. Difficulties may arise in accepting the scenarios, but not the cost-benefit or economic conclusions which should be viewed by the decision maker in context with other relevant, noneconomic impacts and factors.

The results of the cost-benefit analysis are presented in table VIII. Computations were performed using the computer program presented in the appendix. For each scenario the impact of benefit underachievement and cost overruns at the 25 percent level were also included to provide additional insight into the analysis sensitivity.

The active space program scenario is seen to be economically meritorious; BCR = 12.4, IROR = 37 percent. Even when program costs and benefits are revised to allow for 25 percent errors the scenario is quite attractive; BCR = 7.5 and IROR = 30 percent.

A "realistic" program scenario is considerably weaker than the active program picture just discussed; BCR = 2.5 and IROR = 18 percent. This is further weakened when the possibility of overruns and underachievement are considered. Three variations of this scenario were evaluated.

(1) Considering that mission requirements are probably purchased about two years before the mission date, the realistic scenario is improved slightly.

(2) When one allowed for a lump sum benefit accrual beyond 2000, aggregated at 2010, additional improvement in the economic results is seen. Considering the potential new technologies beyond 1982, however, the meaningfulness of such a benefit past 2000 is not very clear.

(3) Combining both possibilities of items 1 and 2 above, further improvement in the economics is observed. The justification of this estimation of benefits though is not very strong.

R&T expenditures in this area of space silicon cells would have considerable spillovers or indirect benefits in the area of terrestrial solar cells. The Department of Energy is seeking to reduce the cost of terrestrial cells from the current $15 to $20/W to $0.50 by 1986 and to $0.10 to $0.30 by 2000. In order to bring about a reduction of two orders of magnitude, major developments in the technology and manufacturing methods would be necessary. When one considers that by 1985 a demand of 500 MW/year for terrestrial cells is forecast, one realizes the magnitude of potential savings that could materialize due to transfer of technology from this space effort. These spillovers were not included in the numerical evaluation of benefits resulting from this program; however, judging by past experience of technology transfer from space programs there is little doubt that major benefits would accrue in the present case where the two areas are so closely related.

Case Study Conclusion

Economic analysis of proposed R&T effort in the area of space solar cells was undertaken. The results are presented and interpreted.

This report summarizes to the decision maker the economic aspects of the expenditure. However, the decision of approving/disapproving an undertaking could not be relegated to economics - which is only a tool. Managerial and policy decision making encompass assessment of political, social, institutional, and other impacts in addition to economic factors.

CONCLUDING REMARKS

Economic analysis provides tools to enhance management decision making. Cost-benefit analysis seeks to summarize and evaluate the economic aspects of decision making. It must be remembered, however, that decision making encompasses legal, social, economic, political, and environmental impacts. - all of which must be assessed; in other words, economics is but one dimension to be assessed by a decision maker.

This report, although limited in scope, can provide the practicing engineer with adequate background to undertake an economic comparison of alternative projects. Thus, analysis would be undertaken at a point where an objective may be achieved by approach X or approach Y. It allows a technical person to make the economic comparison between alternatives X and Y.

Managers realize that virtually all significant aspects of today's events are related to decisions made months, even years, ago. Decisions made today dictate courses of action in the future. Therefore, CBA attempts to take the foreseeable future into account quantitatively in today's decisions. (Sometimes one gets the impression that cost-benefit analysis is a marketing tool within an organization; as though it is a means of justifying expenditures. The drunk and light pole analogy is in order; in this case, the decision maker uses economic analysis for support rather than enlightenment. Needless to say this is not the appropriate role of CBA in decision making and planning.)

A cost-benefit study progresses through stages as outlined below:

1. Gaining familiarity with CBA, welfare economics, and economics in general.

2. Learning about the project, its nature, objective, and history.

3. Writing, and reaching agreement on, project objectives, inputs/outputs, as well as its time horizon.

4. Enumerating alternatives along with the associated costs and benefits of each.

5. Converting, whenever possible, all costs and benefits to dollar equivalents or analogs.

6. Determining (from OMB) the appropriate rate of discount and carrying out the necessary computations.

7. Documenting the work through: a discussion of CBA, problem analysis, discussion of prices used, presentation of CBA results, discussion of results emphasizing intangible effects and any special factors.

In conclusion, it is evident that no project assessment is complete without a review of the associated economic factors. This work outlines how cost-benefit analysis satisfies such a role in some Government expenditures.

APPENDIX

The computer program that follows carries out the numerical manipulations and calculations associated with cost-benefit analysis.

Input data necessary is as follows:

Data card no. 1:	Columns 11 to 60: Any title.
Data card no. 2:	Columns 1 to 10: Interest or discount rate entered as a percent and including a decimal point.
	Columns 11 to 20: Percent of benefits achieved - for sensitivity analysis and including a decimal point. When left blank, 75 percent is assumed in the program.
	Columns 21 to 30: Percent of costs incurred or cost overrun - for sensitivity analysis and including a decimal point. When left blank, 128 percent is assumed.
Data card(s) no. 3:	Columns 1 to 4: Calendar year (the first year to appear represents first year when some expenditures arise or when a decision has to be made).
	Columns 5 to 16: Costs during said year.
	Columns 17 to 28: Benefits during said year (repeat as many data cards no. 3 as there are years during which a cost and/or a benefit occur).
Last card:	Blank card must follow each case. When analysis consists of one case only, a blank card must follow.

```
C      COST-BENEFIT  ANALYSIS PROGRAM.
C      INPUT CONSISTS OF INTEREST(DISCOUNT RATE AND ANNUAL COSTS/BENEFITS.
C      OUTPUT CONSISTS OF ALL INPUT, DISCOUNTED(PRESENT VALUE)
C        OF COSTS/BENEFITS, NET PRESENT VALUE (NPV), BENEFIT COST RATIO (BCR),
C        AND INTERNAL RATE OF RETURN (IROR).
C      ITERATIVE ALGORITHM CONVERGES ON IROR WITH A TOLERENCE OF+/- 0.01.
       DIMENSION NYR(100), COST(100), BNFT(100)
       REAL INTST, NPV, INCR, NPVB, NPVC, NPVBC
       IN = 5
       IOUT = 6
       WRITE (IOUT, 200)
   200 FORMAT ( 1H1, ////)
     1 READ (IN, 100, END= 4000)
   100 FORMAT(10X,'
       WRITE (IOUT, 100)
       READ ( IN, 300) IRST, B1, C1
   300 FORMAT (3F10.0)
       INTST = IRST/100.
       IF ( B1 .EQ. 0. ) B1 =75.
       IF ( C1 .EQ.  0. ) C1 = 125.
       B = B1/100.
       C= C1/100.
       DO 10 N = 1, 100
       READ ( IN, 400, END = 4000 ) NYR(N), COST(N), BNFT(N)
       IF(NYR(N) .EQ.0 .AND. COST(N) .EQ. 0 .AND. BNFT(N) .EQ.0)GO TO 20
    10 CONTINUE
   400 FORMAT ( I4, 2F12.0)
    20 PVC =0.
       PVB =0.
       N = N - 1
       DO 30 I = 1, N
       K = NYR(I) - NYR(1)
       PVC = PVC + COST(I)/(1. + INTST)**K
    30 PVB = PVB + BNFT(I)/(1. + INTST)**K
       NPV = PVB - PVC
       NPVB = PVB * B - PVC
       NPVC = PVB - PVC * C
       NPVBC = PVB * B - PVC * C
       BCR = PVB / PVC
       BCRB = PVB * B / PVC
       BCRC = PVB / ( PVC * C )
       BCRBC = ( PVB * B ) / ( PVC * C )
       WRITE (IOUT, 500)
   500 FORMAT(/// 10X, 'YEAR', 10X, 'COST', 10X, 'BENEFIT'/)
       WRITE(IOUT, 600) ((NYR(I), COST(I), BNFT(I)), I=1, N)
   600 FORMAT(10X, I4, 5X, E11.4, 4X, E11.4)
       WRITE(IOUT, 650) B1, B1, C1, C1
   650 FORMAT(// T100, F4.0, '% OF BENEFITS'/ T48, 'AS OUTLINED',
      G        T63, F4.0, '% OF BENEFITS', T83, F4.0, '% OF COSTS',
      H        T102, F4.0, '% OF COSTS')
       WRITE(IOUT, 700) IRST , PVC, PVB, NPV, NPVB, NPVC, NPVBC, BCR,
      Z  BCRB, BCRC, BCRBC
   700 FORMAT(// T10, 'INTEREST RATE USED', T47, F5.1,'%' //
      B    T10, 'TOTAL PRESENT VALUE OF COSTS', T47, E11.4  //
      C    T10, 'TOTAL PRESENT VALUE OF BENEFITS', T47, E11.4//
      D    T10, 'NET PRESENT VALUE OF PROJECT (NPV)', T47,E11.4,T64,E11.4,
      E    T84, E11.4 , T103, E11.4//
      F    T10, 'BENEFIT-COST RATIO (BCR)', T47, F5.1, T64, F5.1,
      K    T84, F5.1, T103, F5.1//)
       INCR = INTST
```

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      PV1 = NPV
      K =0
   40 CONTINUE
      K = K + 1
      IF ( K.GT. 100 ) GO TO 3500
      IF ((NPV/PVB).GE. -0.01 .AND. (NPV/PVB) .LE. 0.01 ) GO TO 3000
      IF ((NPV/PVC) .GE. -0.01 .AND. (NPV/PVC) .LE. 0.01) GO TO 3000
      IF(INCR .LT. 0.0005) GO TO 3500
      IF ( NPV .GT. 0 .AND. PV1 .GT. 0) INTST = INTST + INCR
      IF ( NPV .GT. 0 .AND. PV1 .GT. 0) INCR = 0.10
      IF ( NPV .GT. 0 .AND. PV1 .LT. 0) INTST = INTST +INCR
      IF ( NPV .GT. 0 .AND. PV1 .LT. 0) INCR = INCR / 2.
      IF ( NPV .LT. 0 .AND. PV1 .GT. 0) INTST = INTST - INCR / 2.
      IF ( NPV .LT. 0 .AND. PV1 .GT. 0) INCR = INCR/2.
      IF ( NPV .LT. 0 .AND. PV1 .LT. 0) INTST = INTST - INCR
      IF ( NPV .LT. 0 .AND. PV1 .LT. 0) INCR = INCR
      PVC =0.
      PVB = 0.
      DO 50 I = 1, N
      K = NYR(I) - NYR(1)
      PVB = PVB + BNFT(I) / (1. + INTST )**K
   50 PVC = PVC + COST(I) / (1. + INTST )**K
      PV1 = NPV
      NPV = PVB - PVC
      GO TO 40
 3000 INTST = INTST*100.
      WRITE (IOUT, 800) INTST
  800 FORMAT ( 10X, 'INTERNAL RATE OF RETURN (IROR) =', T47, F5.1 ,
     A    ' %' // 1H1 ///)
      GO TO 1
 3500 CONTINUE
      INTST = INTST * 100.
      WRITE ( IOUT, 900) K, INTST, NPV, PVB, PVC, INCR
  900 FORMAT ( //// T2, '******'/ T3, '******'/ T4, '******'//
     S         T5, 'AFTER', I4, ' ITERATIONS, IROR ALGORITHM HAS NOT CONVE
     TRGED.'/ T5, 'AT A DISCOUNT RATE OF', F5.1,'% NET PRESENT VALUE ='/
     U T5, 'PRESENT VALUE OF BENEFITS =', E11.4/
     V T5, 'PRESENT VALUE OF COSTS =', E11.4/
     W T5, ' THE INCREMENT FOR THE DISCOUNT RATE IS=, E11.4',1H1//)
 4000 CONTINUE
      STOP
      END
```

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TITLE: SAMPLE COMPUTER PROGRAM INPUT | PROJECT NUMBER | ANALYST | SHEET ___ OF ___

STATEMENT NUMBER | CONT | FORTRAN STATEMENT | IDENTIFICATION

```
      FIRST ILLUSTRATION CASE - 7/21/77
10.
1977  2000000.00
1977                3000000.00
1981                4000000.00
```

NASA-C-836 (REV. 9-14-59)

SUGGESTED READINGS

(Note: This list is not extensive by any means. It seeks to provide some economic understanding and intuition to a technical person.)

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Harberger, A. C.; and Wisecarver, Daniel, eds.: Benefit Cost Analysis 1971 - An Aldine Annual. Aldine-Atherton, 1972.

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Samuelson, Paul: Economics. McGraw-Hill Book Co., Inc., 1976.

Turvey, Ralph: Economic J. Present Value vs. Internal Rate of Return. Vol. 73, Mar. 1963, pp. 93-98.

TABLE I. - CALCULATION OF IROR

[There is little justification in refining the IROR solution to any decimal places given the uncertainties involved in the cost, benefit, and dates data.]

Year	Project transaction
0	-2 M (cost)
2	3 M (benefit)
4	4 M (benefit)

i, %	Trial and error solution for IROR
10	$NPV = -2 + \frac{3}{(1+0.1)^2} + \frac{4}{(1+0.1)^4} = -2 + \frac{3}{1.210} + \frac{4}{1.464}$ $= -2 + 5.21 = +$
30	$NPV = -2 + \frac{3}{(1+0.3)^2} + \frac{4}{(1+0.3)^4} = -2 + \frac{3}{1.69} + \frac{4}{2.856}$ $= -2 + 3.18 = +$
50	$NPV = -2 + \frac{3}{2.250} + \frac{4}{5.062}$ $= -2 + 2.32 = +$
60	$NPV = -2 + \frac{3}{2.560} + \frac{4}{6.554}$ $= -2 + 1.78 = -$
55	$NPV = -2 + \frac{3}{2.402} + \frac{4}{5.772}$ $= -2 + 1.94$
54	$NPV = -2 + \frac{3}{2.372} + \frac{4}{5.624}$ $= -2 + 1.98$
53	$NPV = -2 + \frac{3}{2.341} + \frac{4}{5.480}$ $= -2 + 2.01$

IROR ≈ 53%

TABLE II. - BENEFIT COST RATIO

	Year	Investment A	Investment B
Expenditure	0	-1	-1
Benefit	1	2	0
Benefit	10	0	5
B/C - 10%		1.8	1.9
IROR, %		100	18

TABLE III. - BENEFIT COST RATIO

	Year	Investment X	Investment Y
Expenditure	0	-1	-1
Benefit	1	2	0
Benefit	8	0	5
B/C - 10%		1.8	2.3
IROR, %		100	22

TABLE IV. - BENEFIT COST RATIO

	Year	Investment I	Investment II
Expenditure	0	-1	-1
Benefit	1	2	0
Benefit	4	0	5
B/C - 10%		1.8	3.4
IROR, %		100	50

TABLE V. - SELECTED R&T WORK ON SOLAR CELLS (1977 TO 1982)

[All figures in $K.]

Task	1977	1978	1979	1980	1981	1982
Thin high efficiency	550	325	555	665	475	340
Cell characteristics	287	220	500	500	500	500
Radiation	---	50	50	45	45	45
Metallization	---	50	50	45	45	45
Substrates	---	70	70	100	120	175
Annual total	837	715	1225	1355	1185	1125

TABLE VI. - PROPOSED SOLAR CELL IMPROVEMENT

Year	Efficiency, %	$/W	W/kG
1977	(13.5)	100	50
1981-1982	13.5	5	100
	Savings	$95	

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TABLE VII. - POSSIBLE SPACE ACTIVITY LEVELS

Realistic space program				Aggressive space program		
Mission	Peak, kW	$M saved	Year	Mission	Peak, kW	$M saved
Shuttle augmentation	50	4.75	1984	Shuttle augmentation	50	4.75
Communications, exploration, and observation	10	.95	1986	Space construction	120	11.40
Communications, exploration, and observation	10	.95	1988	Communications, exploration, and observation	20	1.90
Space construction	100	9.50	1990	Public service	500	47.50
Communications, exploration, and observation	20	1.90	1992	Communications, exploration, and observation	50	4.75
Communications, exploration, and observation	20	1.90	1994	SPS prototype	2000	190.00
Communications, exploration, and observation	20	1.90	1996	Communications, exploration, and observation	50	4.75
Communications, exploration, and observation	20	1.90	1998	Communications, exploration, and observation	50	4.75
Public service	500	47.50	2000	Communications, exploration, and observation	50	4.74
	[a](500)	[a](47.50)	[a]2010			

[a]One scenario in the analysis assumes a lump sum benefit, past 2000, appearing in 2010.

TABLE VIII. - CBA RESULTS FOR SPACE PROGRAM SCENARIOS

[Analysis results shown parenthetically represent the combined case of 25% cost overrun and 25% benefit underachievement.]

	Realistic	Realistic + 2 yr	Realistic + 2010	Realistic + 2010 + 2 yr	Active
B/C ratio (10%)	2.5 (1.5)	3.0 (1.8)	2.9 (1.8)	3.5 (2.1)	12.4 (7.5)
IROR, %	18 (13)	23 (16)	19 (14)	24 (17)	37 (30)
NPV (10%), 1977 $M	7.6 (3.2)	10.3 (5.2)	9.7 (4.7)	12.7 (7.0)	57.4 (40.5)

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15. Supplementary Notes

†NASA Summer Faculty Fellow, 1977.

16. Abstract

The methodology of cost-benefit analysis is reviewed and a case study involving solar cell technology is presented. Emphasis is placed on simplifying the technique in order to permit a technical person not trained in economics to undertake a cost-benefit study comparing alternative approaches to a given problem. The role of economic analysis in management decision making is discussed. In simplifying the methodology it has been necessary to restrict the scope and applicability of this report. This work would permit comparisons of Government project alternatives not running into scores of millions of dollars. Additional considerations and constraints are outlined. Examples are worked out to demonstrate the principles. A computer program which performs the computational aspects appears in the appendix.

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